Continuing Towards More Sophisticated Compositional Interpretations of Silicate-Rich Lithologies on the Surfaces of Asteroids.

J. M. Sunshine, jessica.m.sunshine@cpmx.saic.com, Science Application International Corporation (SAIC), 4501 Daly Drive, Chantilly, VA, 20151.

Introduction: Recent studies of silicate-rich asteroids based on rotational spectra, spectra of ever smaller size bodies, and data from the *Galileo* flybys indicate increasing spectral variability even among single objects [*e.g.*, 1-3]. As we continue to better observe lithologies in their geologic context on the surfaces of asteroids, a complementary improvement in our ability to make compositional inferences from spectra is highly desirable. The Modified Gaussian Model (MGM) was specifically developed to quantitatively resolve the extensive overlap among the diagnostic silicate absorptions and thus enhance our ability to remotely determine mineralogy [4]. While the MGM has proven to be a very powerful tool (for example in assessing basaltic lithologies on Mars [5]), there are three areas in which further work is necessary if we are to maximize our understanding of the composition and petrologic significance of lithologies on asteroids such as 433 Eros and 4 Vesta. (1) Accurately resolving the composition of olivine and pyroxene in mixtures; (2) understanding how absorptions in pyroxene affect the remote identification of plagioclase; and (3) continuing to attempt to spectrally resolve both high- and low-calcium pyroxene in spectra which visually appear to contain only one intermediate pyroxene composition.

Approach: By modeling spectra as a sum of absorption bands superimposed onto a linear continuum (in log reflectance and energy), the physically based MGM model provides a framework for deconvolving spectra into their constituent absorption bands [4]. However, given the high degree of overlap among absorption in the major rock forming minerals (high-calcium pyroxene, low-calcium pyroxene, olivine, and plagioclase) simply applying the MGM to spectra of lithologies containing combinations of these minerals will produce erroneous results. For example, previous experiments with a natural mixture of olivine and pyroxene showed that even in high quality laboratory data, absorptions derived from the mixture spectra did not match those found in the olivine and pyroxene separates [6]. Furthermore, currently available remote data have both lower signal-to-noise and spectral resolution than laboratory data. Experience in modeling remote data has shown that simple application of the MGM results in absorptions that also have properties which are inconsistent with known variations [6-7]. Despite these complications, the MGM can be a powerful tool for analyzing mixture spectra if additional physically based constraints are applied to the modeling. For example, using constraints based on the range of observed variations in absorptions in olivine across its solid solution series led to a successful analysis and estimate of the chemical composition of the olivine-rich asteroid 246 Asporina [7].

Olivine and Pyroxene Mixtures: The MGM has been successfully applied in the laboratory to quantify compositional variations of olivine spectra and pyroxene mixture spectra, providing a solid basis for interpretation of unknown spectra. However, olivine-pyroxene mixtures contain four absorption bands in the 1.0 µm region which overlap significantly. The same constraints among olivine absorptions derived from the lab and used for the analysis of Asporina should provide physically realistic solutions to olivine-pyroxene mixture spectra. However, before attempting to model the spectra of asteroids, many of which appear to be mixtures of olivine and pyroxene, the method must first be tested on carefully controlled laboratory samples. The spectrum of Twin Sisters Dunite is an excellent test candidate. Twin Sisters Dunite is a natural olivine-pyroxene mixture for which the spectral properties of both the olivine and pyroxene separates are known. Further tests are carried out using noise and spectral sampling typical of remotely acquired data.

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Pyroxene and Plagioclase Absorptions: The presence of plagioclase on asteroids such as Vesta has been inferred from spectra based on a broad absorption feature centered at 1.2 µm [*e.g.*, 8]. However, pyroxenes also have an absorption in the 1.2 µm region. The absorption in pyroxene is strongest in high-calcium pyroxene, but also occurs in low-calcium pyroxene [*e.g.*, 4]. Given the almost complete overlap between pyroxene and plagioclase absorptions at 1.2 µm, this spectral ambiguity is unlikely to be resolved mathematically. Nonetheless, careful quantitative studies of pyroxene-plagioclase mixtures are underway in an effort to provide guidelines for interpretation of remote spectra. Efforts are focused on determining if the width of the 1.2 µm absorption and/or the relative strength of the 1.0 µm and 1.2 µm absorptions provide indications of plagioclase abundance.

Pyroxene Compositions: Pyroxene spectra, with their diagnostic absorptions near 1.0 and 2.0 µm are broadly speaking readily interpretable. In general, band position is related to iron and calcium abundance, with low-calcium pyroxene at shorter wavelengths than high-calcium pyroxene. However, many spectra have pyroxene band centers that lie at intermediate positions and thus are inferred to have intermediate pyroxene compositions. More likely, such compositions represent averaging at some scale. Given sufficient cooling times, intermediate compositions will exsolve into high- and low-calcium phases. In more rapid cooling environments, such as thin flows on the surface of the Moon, the pyroxenes are unable to exsolve and instead exhibit extreme zonation. Using the MGM it is possible to distinguish between these two scenarios [10]. In several cases, most notably *ISM* spectra of the surface of Mars [5], it has been shown that spectra which appear with traditional techniques to have one set of intermediate pyroxene absorptions are in fact mixtures composed of two distinct pyroxene compositions in various proportions. In contrast spectra of lunar pyroxenes, even with the MGM cannot be resolved into high- and low-calcium components. However, these lunar sample have anomalous wide absorption bands which are indicative of the averaging due to zonation [10]. To explore the role of pyroxene mixtures and their implications for asteroid compositions and cooling rates, efforts are underway to examine pyroxene absorptions in meteorite spectra, beginning with HED samples.

Advances in each of the above areas will allow for more sophisticated compositional interpretations of remotely acquired spectra of silicate-rich bodies. Accurate understanding of the relative abundance and chemical composition of olivine, low-calcium pyroxene, high-calcium pyroxene, and plagioclase provides key constraints for petrologic modeling. The combination of such enhanced compositional information and geological context will allow us to more fully understand the geologic history and significance of asteroids. The notable variations observed in rotational spectra of 433 Eros [9] suggest that the upcoming NEAR encounter with Eros will prove a fertile and exciting place to apply these new techniques.

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